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Competing goals draw attention to effort, which then enters cost-benefit computations as input

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Abstract: Different to Kurzban et al., we conceptualize the experience of mental effort as the subjective costs of goal pursuit (i.e., the amount of invested resources relative to the amount of available resources). Rather than being an output of computations that compare costs and benefits of the target and competing goals, effort enters these computations as an input.

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such resources but then attribute the effects they discuss to the rational allocation of *mechanisms* to higher priority tasks.

I turn now to the main substance of the target article. The authors argue that, by adding a mechanism that rationally allocates processors (occupiable resources) to tasks, they can render their processor account superior to the depletable-resources account. Their argument is convincing. However, it is not fair or balanced. They have shown that an occupiable-resource account that incorporates a rational allocation mechanism is superior to a depletable-resources account that does not incorporate such a mechanism. It is perfectly possible to rationally allocate depletable resources – electricity suppliers do it when faced with a large unexpected loss of generating capacity. A mechanism precisely analogous to the one that the authors describe could be added to the depletable-resources account.

If this were done, it is unlikely that the resulting model would be inferior to the one proposed by Kurzban et al. There is no reason to suppose that prioritization of resources using opportunity costs would be any less effective than prioritization of processors using opportunity costs in explaining all the phenomena that the authors discuss. For example, effects of incentives and availability of alternative tasks, such as using a smartphone, could be handled equally well. Furthermore, one could still argue, as the authors do, that "*the sensation of 'mental effort' is the output of mechanisms designed to measure the opportunity cost of engaging in the current mental task*" (sect. 2.3.2, para. 2, italics original).

It might prove difficult to design experiments to distinguish the occupiable-resources account and the depletable-resources account of performance decrements if a rational resource allocation mechanism were added to both types of model. Recovery rates after demanding performance may provide one line of attack.

Unfortunately, there is a third possibility. Both processors and depletable resources may be rationally allocated to tasks. Distinguishing this alternative from the other two is likely to pose further difficulties.

Finally, I consider the authors' argument that there are no proposals that identify an explicit neural resource beyond Gaillot and Baumeister's (2007) argument in favour of glucose. Kurzban et al. say that any such proposals would need to explain: "(1) what the resource is, (2) how that resource is depleted by effortful tasks, (3) how depletion of the resource is sensed and leads to subsequent decrements in task performance, and (4) why some kinds of mental/neural activity, but not others, lead to resource depletion" (sect. 4.1, para. 6).

These seem very stringent conditions for classifying something as a depletable neural resource. There are many neurological problems, such as Parkinsonism, where performance decrements can be attributed to some neural resource (e.g., a neurotransmitter or neurohormone) that cannot be renewed at the rate at which it is depleted. In such cases, the resource has been primarily depleted not by an effortful task but by disease. Effective drug treatments replace the resource. In cases such as this, the depletable resource is not fuelling the processor but acting as a means of signalling for it. However, its depletion still causes performance impairment.

Kurzban et al. appear to exclude depletable resources that serve as signals rather than as fuels from their definition of a depletable resource. For example, though they say they know of no proposals for an explicit neural resource beyond glucose, they still suggest that information about opportunity costs needed for rational allocation may be provided by levels of a neurotransmitter, such as dopamine. This looks like a depletable-resource account: It predicts that chronic depletion of dopamine via disease or experimental manipulation will lead to an inability to regulate its levels in the prefrontal cortex for signalling purposes, and that, as a result, rational allocation would be impaired.

Distinguishing occupiable and depletable resources at the neural level is open to the criticism that all brain constituents are subject to chemical turnover. Ultimately, it is the rate of this turnover that should allow us to distinguish resource types. Occasionally, I need to replace parts of my car when they are broken or worn out. This does not mean that my car is a depletable rather than an occupiable resource: I have to replace parts of my car much less frequently than I have to re-fill it with fuel.

Competing goals draw attention to effort, which then enters cost-benefit computations as input

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Abstract: Different to Kurzban et al., we conceptualize the experience of mental effort as the subjective costs of goal pursuit (i.e., the amount of invested resources relative to the amount of available resources). Rather than being an *output* of computations that compare costs and benefits of the target and competing goals, effort enters these computations as an *input*.

Kurzban et al. argue that mental effort experienced during task engagement is a function of opportunity costs – that is, the degree to which the mental processes allocated to a target task or goal are not available for other tasks or goals. We consider this idea intriguing and concur that feelings of effort, like other sensations, are most likely the outputs of mechanisms designed to produce inputs to decision-making systems (Bloom 2010; Thornhill 1998). We doubt, however, an additional assumption of the model, namely, that the experience of effort itself changes as a function of the presence of competing goals. We propose a potential alternative account of subjective feelings of effort and their adaptive value. Accordingly, subjective effort emerges from cost computations associated exclusively with the currently pursued goal and is a function of the means invested into the goal at hand and the means available for pursuing it. In our conceptualization, alternative goals do not enter this computation through opportunity costs. The presence of competing goals may, however, draw more *attention* to the resources and, in turn, the effort invested into pursuing the target goal.

Our account of mental effort differs from Kurzban et al.'s account regarding the effect of competing outcomes. Kurzban et al. predict that competing goals increase mental effort through opportunity costs, that is, the degree to which resources invested into the target goal are not available for achieving competing goals. In our view, subjective effort is a function of the resources a person perceives to invest into the pursuit of the target goal in relation to the subjectively available goal-relevant resources (e.g., when time is crucial for pursuing the target goal, perceived effort is mainly based on how much of one's available time is spent for its pursuit). Based on the definition of goals as cognitive representations linking means to desired outcomes (e.g., Freund et al. 2012; Kruglanski et al. 2002), the subjective perception of effort should be related to the *means* of goal pursuit (i.e., how many resources does one have to invest to attain the outcome?). Kurzban et al. posit that mental effort is related to potential *outcomes* or alternative goals, but it remains unclear how people gauge the effort if they do not do so on the basis of how many resources they invest relative to the resources they have available for the pursuit of a target goal. By reflecting these relative costs, subjective feelings of effort provide an informational basis for further cost-benefit computations that determine whether an individual decides to continue investments into the goal at hand or turn away from it and towards other goals. As costs during task engagement accumulate over time, the feeling of mental effort during task engagement increases simultaneously (cf. Boksem & Tops 2008). In agreement with Kurzban et al., and contra to previous accounts of mental effort (Kahneman 1973), we consider mental effort not a finite capacity but a metacognitive phenomenon that signals the ratio of the finite amount of available resources to the subjectively invested ones.

How, then, is the subjective experience of effort influenced by potential alternative goals? We posit that perceiving alternative desired outcomes draws *attention* to the means of goal pursuit to determine whether such outcomes require the same means. The presence of competing outcomes should make people become more aware that their resources are finite and have to be spent carefully, that is, that they are best invested in means that yield the most valuable outcome (e.g., Ebner et al. 2006).

Each alternative goal has an (expected) cost/benefit ratio. In order to compare multiple goals, a person needs to make a rough overall estimate as to how many resources will be needed and are available to attain the goals. Hence, a person should compare the experienced cost/benefit ratio of the ongoing goal against the expected cost/benefit ratio of additional or alternative goals. In this way, the mental effort invested into goal A enters cost-benefit computations that compare target goal A to the alternative goal B (note that goal B might also be to pause the pursuit of a target goal in order to conserve resources; Boksem & Tops 2008; Hennecke & Freund, in press). The presence of alternative goals creates a reference against which the cost/benefit ratio of the ongoing goal-pursuit is compared. By triggering this comparison, alternative goals draw attention to the effort – as a subjective representation of the costs – invested into the ongoing goal. Without changing subjective effort directly, alternative goals might thus change the *perception* of effort by putting it into the center of attention (Kool et al. 2010). By providing information about the means/resources a person currently invests into the pursuit of a goal, subjective effort allows a rough estimate of how many resources are available for the pursuit of additional or alternative goals. It may thereby serve as an important metacognitive cue as to whether to continue with the current goal or to switch to an alternative goal. This function would be undermined if subjective effort were affected by the presence of alternative goals. Note that this conceptualization of subjective effort does not imply that it is a veridical reflection of the actual costs and resources a goal requires. A person might very well underestimate goal requirements and/or available resources, which might then lead to such phenomena as the planning fallacy (Buehler et al. 1994).

Important in the current context, however, is that our conceptualization of subjective effort should be unaffected by the presence of competing outcomes. Rather than being an output of computations that consider (potential) costs and benefits of the current and the competing goal, effort enters these computations as a subjective representation of the costs of the current goal. As proposed by Kurzban et al., experiments that assess and compare perceived mental effort under different concurrent task conditions are needed to compare both accounts.

Persisting through subjective effort: A key role for the anterior cingulate cortex?

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Abstract: One shortcoming of Kurzban et al.'s model is that it is not clear how animals persist through subjectively effortful tasks, particularly over a long time course. We suggest that the anterior cingulate cortex plays a critical role by encoding the utility of an action, and signalling where efforts should be best directed based on previous and prospected experience.

Kurzban et al.'s model aligns well with emerging metacognitive proposals of fatigue and effort, and provides a useful account of why task switching occurs. However, under many circumstances individuals continue to persist in a primary task where the immediate costs are considerable and where alternative options present significant benefits. As an example, in academia the tangible rewards of funding, publication, and tenure are far removed from the months of executive-function–demanding writing, research, and teaching required to reach these goals. The level of persistence needed in such scenarios is not well accounted for in the proposed model, which predicts that the large opportunity costs associated with long-term goals should prompt a high mental-effort signal and subsequent re-prioritization of behavior. So how do we sometimes "stay the course" in the face of subjective effort?

Several potential mechanisms could be involved in persistence. While the fatigue signal could be directly attenuated, say, by reward receipt, other mechanisms could operate upstream of this point. For example, the discounting of the primary goal that normally occurs under conditions of temporal distance, uncertainty, or exertion, could be attenuated during the cost/benefit evaluation. Alternatively, the degree of discounting of competing tasks could be increased. Kurzban et al. suggest that the key to task persistence involves attenuating the effort signal through reward, although they are not specific about the underlying brain mechanisms. Here we propose that activity in the anterior cingulate cortex (ACC) is critical, functioning to integrate cost/benefit ratios to provide a relative utility signal that may work directly to suppress subjective effort.

As the target article notes, as ACC activity decreases, so does task performance. One interpretation of this effect is that as long as activity in this region of the prefrontal cortex (PFC) remains high, vigilance and persistence are maintained. We and others have examined single-unit ACC activity during decision tasks and found that heightened firing appears to indicate a worthwhile course of action; however, a sufficiently strong signal may be required to drive pursuit and persistence (Amiez et al. 2005; Hillman & Bilkey 2010; Quilodran et al. 2008; Sallet et al. 2007; Shidara & Richmond 2002). Importantly, this ACC signal appears only when significant cost/benefit analysis is required; furthermore, heightened firing does not always correspond to the most costly action, but rather seems to indicate the most worthwhile choice in terms of relative cost/benefit computed utility (Hillman & Bilkey 2010; Kennerley et al. 2006; Rudebeck et al. 2008). Moreover, the ACC is recruited regardless of the actual type of effort involved – be it physical exertion, competitive fighting, or mental taxation – suggesting that the region may be responding to generalized opportunity cost calculations inherent in cost/benefit decision tasks.

These encoding characteristics of ACC match the descriptions of several of the opportunity cost model components illustrated in Figure 1 of the target article: The ACC's experience-based encoding of cost/benefit computations provides an output signal that drives allocation of cognitive processes towards completion of tasks with optimal utility. Viewing the ACC in this way – as a dynamic utility encoder versus a cost encoder – represents a minor but important shift in thinking, one that could account for the persistence signal missing from the current model. Strong ACC signals could drive task persistence; however, as the ACC output signal wavers ("utility decreasing"), the phenomenology of effort begins, leading to reductions in persistence. Hence, the subjective experience of effort is, we propose, neither the result of the initial ACC recruitment nor the result of low levels of ACC activity, but rather, it results from a *decrement* in ACC activity from some prior, higher level. When tasks